RESEARCH PAPER 37
JANUARY 1961

THE ECONOMIC SIGNIFICANCE OF MORTALITY IN OLD-GROWTH DOUGLAS-FIR MANAGEMENT

BY R. O. MC MAHON

PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
U.S. DEPT OF AGRICULTURE · FOREST SERVICE

Research Paper 37

THE ECONOMIC SIGNIFICANCE OF MORTALITY IN OLD-GROWTH DOUGLAS-FIR MANAGEMENT

by

R. O. McMahon

January 1961

PACIFIC NORTHWEST
FOREST ~~AND RANGE~~ EXPERIMENT STATION
R. W. Cowlin Portland, Oregon

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

CONTENTS

SUMMARY

Current mortality in the Douglas-fir subregion, exclusive of catastrophic mortality, approximates a billion feet a year. The Forest Service report "Timber Resources for America's Future" recommended "...utilizing a substantial portion of the unsalvaged mortality loss..." as one means of permanently increasing the Nation's timber supply and bringing it into better balance with expected future timber requirements. Recovery of mortality from old-growth forests in the Douglas-fir subregion offers special opportunities for acting on this recommendation. Increased recognition of these opportunities is needed.

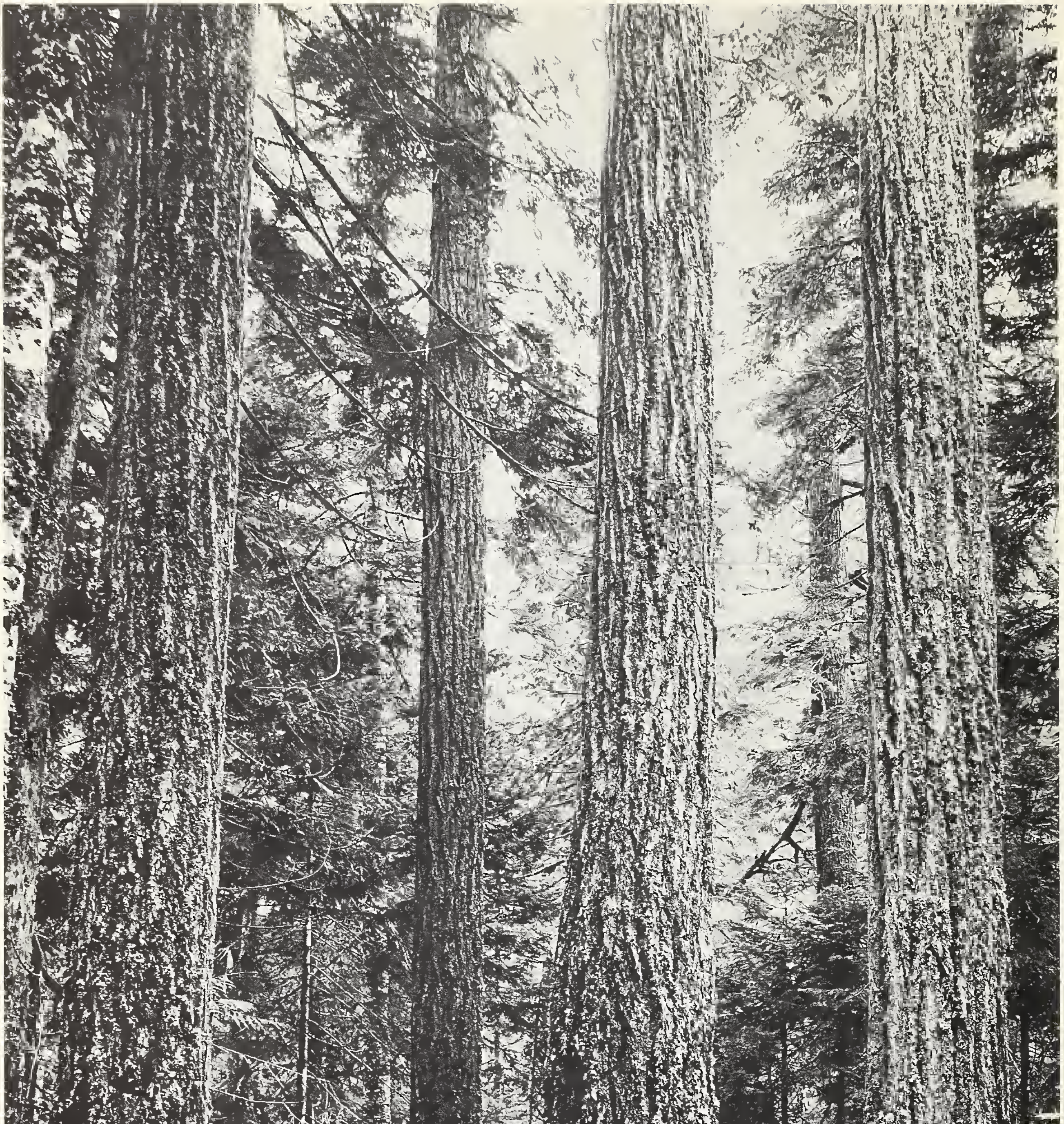
Both industrial and public landowners have begun salvage programs to recover mortality, which emphasizes that salvage of dead and down material is economically feasible in given situations. Some techniques and equipment are available for removing mortality from live stands without causing excess damage to trees and soil. Inaccessibility, once a major obstacle to mortality salvage programs, is less important today. Recent evidence implies that roads in old-growth stands can be constructed well in advance of final harvest, and that interest and maintenance charges and depreciation on part of the capital outlay for these roads can be met by returns obtained from a salvage program. Moreover, nearly 25 percent of old-growth Douglas-fir stands are within one-quarter mile of existing roads today, so abundant opportunities are at hand for beginning salvage operations in leave settings from these existing roads.

The average net annual loss in old-growth Douglas-fir stands, due to enphytotic mortality, approximates 359 board feet per acre, most of which is Douglas-fir and western hemlock in larger size classes. Periodically salvaging this material will increase both the total supply of old-growth Douglas-fir and the total yield obtainable over the life of old-growth stands.

Factors that affect net returns and benefits include (1) quality of stand as determined by stand decadence, species composition, and brush encroachment; (2) cost of salvage logging, which is affected by stand accessibility, salvable volume, and topography; and (3) values obtained in salvage yields and other benefits from a salvage program.

Several aspects of the salvage problem need further clarification. Rates of decay of dead and down material and the salvable life of dead timber of various species are not fully known; gross growth rates in old-growth stands have not been thoroughly studied; nor is the nature and extent of mortality known for old-growth types other than Douglas-fir, which cover an additional 3 million acres in the Douglas-fir subregion. These, too, should eventually be included in periodic salvage-logging programs.

The substantial annual mortality in the Douglas-fir subregion, and the species composition and value, suggest a high national priority for intensifying operations to capture mortality losses.



Old-growth Douglas-fir.

INTRODUCTION

In extent and in proportion of high-quality logs contained, old-growth Douglas-fir stands in the Douglas-fir subregion--western Oregon and western Washington--are a substantial capital asset. These stands of old-growth Douglas-fir and associated species cover some 3 million acres, and for the next 50 to 100 years they will be the primary source of raw material for the forest industry in the subregion. If stumpage were valued at $20 per thousand board feet, these old-growth stands would have a gross worth of $3.3 billion.

Contrary to general belief, old-growth Douglas-fir stands in the subregion are not static. The Douglas-fir component alone may actually show a gross growth per acre of 3 to 558 board feet annually, while total gross growth of all species in these stands may range from 207 to 837 board feet per acre per year (6). However, part of the volume in these stands is lost each year because of death from natural causes (fig. 1). Such loss varies from stand to stand; it may equal and often exceeds gross growth. Moreover, the heaviest loss is concentrated in Douglas-fir, the high-value component of these stands.

This study is concerned with enphytotic mortality, that which occurs more or less regularly from year to year in old-growth stands without changing their identity.

Figure 1.--Western hemlock mortality in an old-growth Douglas-fir stand.

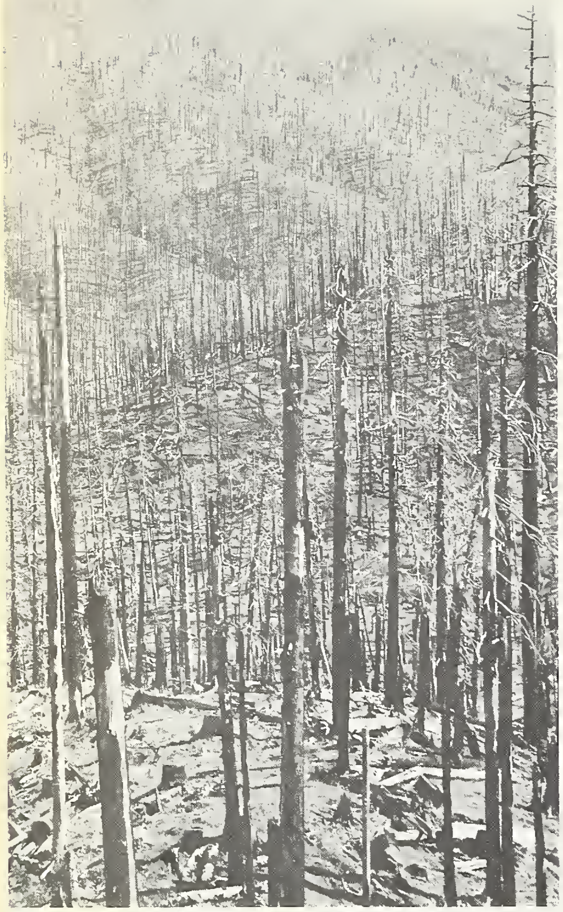


Figure 2.--Fire: one cause of catastrophic mortality.

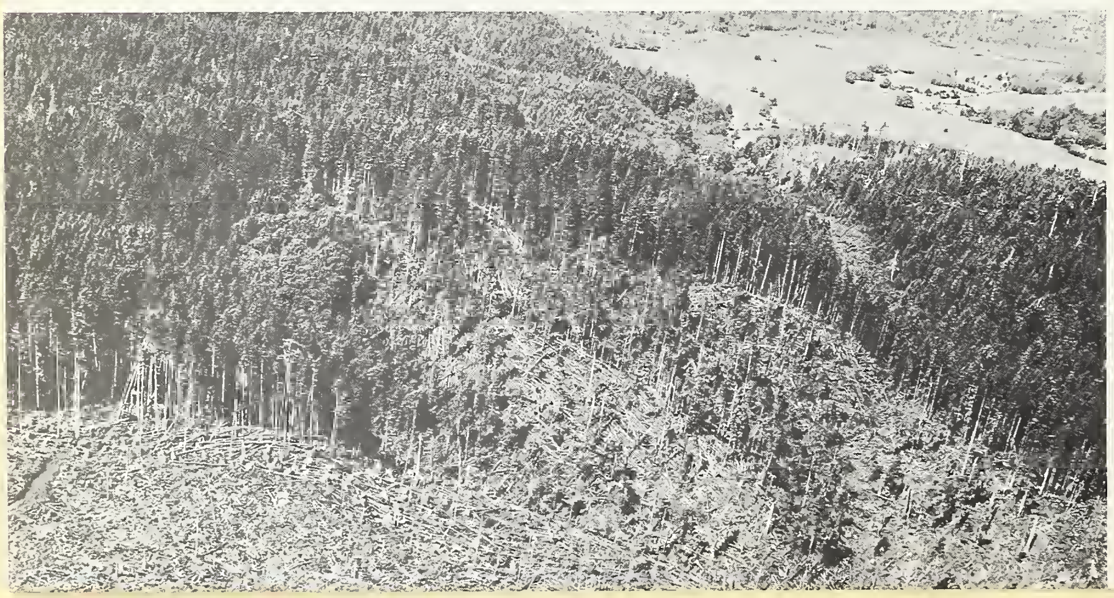
Excluded is catastrophic mortality, that which alters more than 40 acres of a stand to such degree that the area can no longer be classed as old growth (fig. 2).

In the past, inaccessibility of many old-growth stands precluded salvaging mortality until the final cut. This inaccesibility was attributable not only to lack of roads, but also to lack of adequate volumes and values per acre or lack of efficient technology for removing dead and down material.

In recent years conditions have changed. Stumpage and log prices have risen, improved logging methods and equipment have been developed, and many old-growth areas have been opened up with roads. Currently some dead and down material is recovered when old-growth Douglas-fir stands are clear cut. Blowdown around the edges of a setting (fig. 3) is also being salvaged. Such salvage material has an established market in the subregion. It constitutes 15 to 20 percent of the subregion's annual log production and in 1958 amounted roughly to 600 million board feet. Such operations do not recover current enphytotic mortality from inaccessible stands nor from leave settings except for blowdown around the edges of clearcuts.

Annual mortality in unlogged old growth constitutes a greater volume than the 600 million feet of salvage material recovered in

Figure 3.--Blowdown associated with clear cutting.



1958. A small amount of enphytotic mortality is now being recovered from limited areas of old growth on industrial and national-forest lands, mostly adjacent to established roads. Much more could be recovered if a systematic program were begun to reach all old-growth stands periodically.

The recent Forest Service report, "Timber Resources for America's Future," estimated that unsalvaged mortality in all sawtimber stands in the Nation "...was almost 10 billion board feet in 1952" (9, p. 107). The report recommended "...utilizing a substantial portion of the unsalvaged mortality loss..." as one means of permanently increasing the Nation's timber supply and bringing it into better balance with expected future timber requirements.

In the following sections, the rate of enphytotic mortality in the Douglas-fir subregion is estimated and its availability for periodic salvage operations is discussed. Economic considerations relating to salvage logging, and criteria for determining priorities in choice of stands for salvage, are evaluated.

AMOUNT AND AVAILABILITY OF MORTALITY IN SUBREGION

Total Annual Mortality

Some 1,077 million net board feet (enphytotic mortality) are lost annually from the live timber inventory on approximately 3 million acres of old-growth Douglas-fir type remaining in the subregion. Losses average 359 net board feet per acre per year.

This compares favorably with another figure developed by this Station (6) for mortality in old-growth stands during the period 1948-52. It was found that net losses averaged 345 board feet per acre annually, based on Forest Survey data for the southwestern parts of both Washington and Oregon. Mortality by age classes was reported as follows:

	Net mortality per acre per year (Bd. ft.)
Age class (years):	
180-250	280
260-350	351
360+	616
Uneven-aged	248
Average (weighted)	345

Wright and Lauterbach (11) show a gross annual mortality of 1,350 board feet per acre in 180-year-old Douglas-fir over a 10-year period. Their estimate, however, includes catastrophic losses due to blowdown during two winters. This blowdown was followed by severe beetle outbreaks which spread into green timber and caused additional mortality. Average gross loss per acre for the 3 years 1950-52 amounted to 3,770 board feet annually. For the other 7 years, gross losses averaged 338 board feet per acre per year. Over 80 percent of the 10-year loss occurred during a 3-year period. Such heavy losses differ in two ways from that discussed in the current study: (1) volumes are given in gross, rather than net, terms, and (2) volumes in certain years include catastrophic losses which are greatly in excess of the apparent enphytotic mortality.

Steele and Worthington (8) measured mortality in an old-growth Douglas-fir stand on the Wind River Natural Area, and found it to average 759 board feet per acre per year for the 6-year period 1947-53. As in Wright and Lauterbach's study, this is gross volume, and blowdown and beetle attack were unusually heavy during this period. This stand is located in the Columbia Gorge area of Skamania County, Wash., where old-growth stands may not be typical of those in the rest of the Douglas-fir subregion.

The average annual net loss of 359 board feet per acre reported here is based on 342 Forest Survey plots in old-growth Douglas-fir. The sample plots were distributed among 12 counties throughout the subregion that were inventoried between 1949 and 1956. Only sawtimber trees (11 inches d.b.h. and over) were included, and deductions for rot and other defects were made. Thus, the estimate represents sound wood volume suitable for lumber use. This estimate appears consistent with results of other published investigations of mortality, and hence is believed acceptable as a valid estimate of enphytotic mortality for the subregion.

Species Composition and Size Class of Mortality

The average annual net loss of 359 board feet per acre is divided among species and diameter size classes as shown in table 1. Douglas-fir 21 inches d.b.h. and larger accounts for 58 percent of the total annual loss for the subregion. Of this proportion, 59 percent is in trees larger than 40 inches. This constitutes 34 percent of the average annual net loss per acre. Douglas-fir 11 inches and larger d.b.h. constitutes 61 percent of the annual mortality, which corresponds closely to the proportion (57 percent) of Douglas-fir in the total sawtimber volume of the subregion.

Douglas-fir and its major associate in old-growth stands, western hemlock, together account for 83 percent of the net volume loss. The remainder is distributed among nine other species, including two hardwoods.

Table 1.--Mortality in old-growth Douglas-fir stands in the Douglas-fir subregion, by species and diameter size class (inches)

(In percentage of average annual net board-foot loss)

Species	11-20	21-30	31-40	41-50	Over 50	All size classes
	Percent					
Douglas-fir	3	9	15	12	22	61
Western hemlock	5	6	8	3	--	22
True fir (white and Pacific silver)	2	2	2	--	5	11
Western redcedar	1	1	1	1	1	5
Other[1]	([2])	1	--	--	--	1
Total	11	19	26	16	28	100

[1] Includes western white pine, sugar pine, incense-cedar, Pacific yew, red alder, and golden chinkapin.

[2] Less than 0.5 percent.

Mortality occurs predominantly in larger trees--89 percent in trees larger than 20 inches d.b.h., 70 percent in trees over 30 inches, and 44 percent in trees over 40 inches.

Accumulation of Mortality

The amount of salvable mortality in the subregion at any time is a function not only of the rate at which mortality occurs, but also of the rate at which dead wood decays. The gross rate at which enphytotic mortality accumulates is represented by the 359 board feet of net annual mortality. Net accumulation, the amount available for salvage in any given year, is derived by subtracting annual decay from this figure. Net accumulation is important for two reasons: it leads to an index of the salvable life of dead timber; and it also provides the basis for estimating net volume of salvable material available for removal at specified periods. Annual net loss ordinarily is not enough to justify a yearly salvage operation on each acre.

Less is known about decay rates for dead timber of various species in the Douglas-fir subregion than about mortality rates. Wright and Wright (10) have found that rate of decay in beetle-killed Douglas-fir is

related directly to intensity of beetle attack and that volume loss from decay proceeds more rapidly in young trees because they have a higher proportion of sapwood. After 2 years, sapwood generally is no longer suitable for lumber, though some recovery for pulp may be possible even after 3 years. Heartwood begins to deteriorate by the fourth year, and by the sixth year 25 to 50 percent of tree volume is lost, varying with age, size of tree, and other factors. In either case, however, standing dead trees generally decay more rapidly than down timber, particularly if the latter is in a moist, shaded environment.

Childs and Clark (5) investigated decay of heavy windthrow areas in western Washington and northwestern Oregon. They stated that rates of decay are probably quite different for scattered windthrow or trees killed by other causes, than for heavy concentrations of windthrow. They found rates of decay in heavy windthrow to vary with locality and with numerous other factors, the magnitudes and effects of which are known only in general terms. Bearing these qualifications in mind, the following tentative conclusions can be drawn from these studies and applied to scattered enphytotic mortality: Western hemlock and Pacific silver fir can be expected to decay rapidly, Sitka spruce somewhat less rapidly, while Douglas-fir is fairly durable. The sapwood of Douglas-fir, however, decays rapidly. Small logs of all species decay more rapidly than large logs; temperature and site quality are also important controlling factors.

The studies that have been made indicate that delaying salvage operations for a year or two after death ordinarily involves only partial loss, or at most, total loss of sapwood; further delay involves deterioration of heartwood. While volume loss from sapwood decay amounts to a relatively small proportion of merchantable tree volume, the value loss is relatively greater because clear wood is destroyed.

These considerations suggest that recurrent salvage operations in old-growth stands should be spaced at intervals not to exceed 2 years if recovery of maximum volume and value of sound material is desired (fig. 4).

Figure 4.--Roadside salvage of mortality from old-growth Douglas-fir stand. Note decay in logs.

However, 700 net board feet per acre is not enough for an economic logging operation using today's equipment and techniques. A minimum of 1,000 to 1,500 board feet is needed. In all probability, mortality will not be salvaged more often than once every 3 to 5 years, unless it should greatly exceed the net yearly average of 359 board feet per acre on a particular area.

Availability of Mortality for Salvaging

From an economic viewpoint, mortality estimates are not too meaningful unless this material is available for utilization. The following tabulation presents a measure of relative availability of mortality from old-growth Douglas-fir stands in the subregion:

	Proportion of all old-growth Douglas-fir (Percent)
Distance from established road (miles):	
Up to 1/4	23
1/4 to 1/2	15
1/2 to 1	15
1 to 1-1/2	13
1-1/2 to 2	9
Over 2	25
Total	100

Twenty-three percent of old-growth Douglas-fir stands are within one-quarter mile of established roads, whereas 47 percent are over 1 mile from a road, indicating that accessibility constitutes a major problem in salvaging mortality. A solution to this problem of accessibility is offered in the section "Cost of Salvage Logging," where the building of a road system for salvage of mortality in advance of final clear cutting is discussed.

These data on distance from established roads were developed by picking random points in old-growth Douglas-fir on type maps of the six most recently inventoried counties in the subregion. The distance to the nearest road from each of these random points was obtained from current maps, and the points were classified according to the above distance categories. The proportion of total points in each category provides a measure of relative availability of enphytotic mortality.

ECONOMIC EFFECTS OF SALVAGING MORTALITY

Estimates of amount of salvable mortality and its availability in the subregion are two prerequisites for planning large-scale salvage operations. A third is an analysis of economic consequences that can be expected if mortality is salvaged throughout the subregion. These consequences are discussed in this section.

Effect on Total Cut

To analyze the effect of mortality salvage on the subregion's total cut of sawtimber, differing effects from accumulated and current enphytotic mortality must be distinguished. Salvage of accumulated mortality well in advance of final clear cutting will not affect the total cut available from old-growth, assuming that accumulated mortality in the subregion remains more or less constant per acre. This assumption implies an equation between current enphytotic mortality and decay in past mortality for the subregion as a whole. If annual cut remains constant, salvage of accumulated mortality will simply substitute for green timber until all old-growth stands have been opened up and initially salvage logged. During initial salvage logging, the proportion of live timber in the annual cut will be reduced; after, the proportion of live timber cut from old-growth stands will be increased. Theoretically the total yield is not affected because the same amount of accumulated mortality would be harvested when the area was finally clear cut.

Salvaging current enphytotic mortality periodically after initial removal of accumulated mortality, however, will increase the total supply of old growth because timber is used that otherwise would decay and be lost in the absence of periodic salvage operations. If a constant annual cut is assumed and current enphytotic mortality substituted for a part of the annual cut of live timber, then the life of old-growth stands will be extended as well as the total yield increased. This is one very practical way of permanently increasing the Nation's timber supply, as pointed out in "Timber Resources for America's Future" (9).

A more probable outcome, however, is that the subregion's total annual cut will not remain constant. Markets permitting, annual cut could be increased either by cutting more live timber or by adding accumulated and enphytotic mortality to the cut, rather than substituting mortality for a part of the cut. Adding salvaged mortality to annual cut is the preferable choice because it permits increasing the total annual cut without increasing drain on the live timber inventory.

A reasonable conclusion is that the subregion will experience some substitution of salvaged mortality for live timber in the annual cut, together with a gradually expanding total cut. Already the increased demand for stumpage on national forests, particularly by smaller operators, has

resulted in an expanded program of salvage sales. On the other hand, some industrial owners are realizing that just holding old growth until the harvest cut entails unnecessary losses through mortality and decay. Salvaging this mortality would permit its substitution for a company's most expensive purchased wood, thus realizing a savings on total cost of wood procurement.

Effect on Stumpage Price

To the extent that salvage of mortality increases total annual cut, upward pressure on stumpage prices will be reduced because more timber is available to satisfy current demand. And although it has been possible to obtain the same price for salvage as for green timber of comparable quality, consideration could be given to pricing salvage material below other stumpage to encourage and accelerate use of this material. This practice would further reduce upward pressure on stumpage prices by making salvage sales even more attractive.

EVALUATION OF PRIORITIES IN SALVAGING MORTALITY

In deciding when and where to begin salvaging periodic mortality, several considerations need to be taken into account in order to maximize net returns and benefits from such a salvage program. These considerations include (1) quality of the stand, (2) cost of salvage logging, and (3) value of salvage yield and other benefits.

Quality of Old-Growth Douglas-fir Stands

Here, broadly speaking, quality refers to vigor of old-growth stands and a desirable species composition from the viewpoint of stand management. The main criteria considered in this concept are degree of stand decadence, species composition, and extent of brush encroachment. These criteria are important because choices exist with respect to initiating a mortality salvage program. At one extreme are decadent stands developing a progressively poorer species composition and adverse brush conditions. At the other extreme are more vigorous stands, perhaps even with a small net growth per acre, and with little regression in species composition. Securing maximum net returns requires careful selection of stands in which to begin salvage operations.

Degree of stand decadence.--Decadence sets in when annual mortality begins to exceed annual gross growth (fig. 5). To measure decadence, therefore, both gross growth and amount of mortality must be analyzed.

Data on rates of growth in old-growth stands as related to age and stocking are not well established. Some information has been developed,

Figure 5.--Decadent old-growth Douglas-fir stand, showing young hemlock filling in large opening in stand. Numerous snags indicate breakup of stand.

however, suggesting that gross growth may be quite substantial. In undisturbed old-growth Douglas-fir stands in the subregion, gross growth was estimated (6, p. 16) by age classes as follows:

	Gross growth per acre per year (Bd. ft.)
Age class (years):	
180-250	516
260-350	410
360 and over	740
Uneven-aged	431
Average (weighted)	500

The study by Steele and Worthington (8) showed an average annual gross increment of 767 board feet in a 350-year-old Douglas-fir stand in the Wind River Natural Area.

Isaac (6) reports gross growth in old-growth Douglas-fir to range from 207 to 837 board feet per acre per year. Although these measurements were made in stands that had been partially cut during the previous

5 years, growth rates evidently were not correlated with release of trees, according to Isaac's analysis. He reports that while half the trees responded to release, the other half declined in growth rate, and that the acceleration about compensated for the decline. Thus, even though these figures were not obtained in undisturbed stands, they indicate that old-growth stands may have a substantial rate of gross growth. These data underscore a little-recognized fact: as phrased by Steele and Worthington (8), "...it is not for lack of increment but because of mortality that the [old-growth] stand is failing to increase in live-tree volume."

Recent findings reported by Berntsen (1) confirm Steele and Worthington's statement. A mature 250-year stand of Douglas-fir on a high site III showed a gross periodic annual increment of 1,582 board feet per acre for all species, and average annual mortality of 1,156 board feet per acre. Net periodic annual increment thus equaled 426 board feet per acre. Distribution of both periodic growth and mortality among species was found to approximate their proportions of stand volume. Despite heavy mortality, the stand remains in a relatively vigorous condition.

In a previous section, average enphytotic mortality was given as 359 net board feet per acre per year. Variation from stand to stand and year to year can result in a figure ranging from no mortality to perhaps several times the average.

Degree of decadence, then, depends on the particular relation between annual gross growth and amount of mortality. When these two quantities have been estimated, net growth or loss can be established and a basis provided for separating decadent from vigorous stands.

Figure 6.--Stand composition is another aspect of stand quality. Old-growth Douglas-fir in this stand is being replaced by western hemlock and true firs.

Species composition.--Another qualitative criterion of old-growth Douglas-fir is species composition of a stand and trend in composition (fig. 6). High-quality stands are those with a large proportion of volume in Douglas-fir and a relatively small proportion in lower valued associated species; a low-quality stand is one that has lost most of the Douglas-fir component.

Change in species composition becomes pronounced in Douglas-fir stands over 160 years old. Boyce and Wagg (2) present data showing that after 160 years the number of Douglas-fir trees per acre in old-growth stands decreases with stand age, while number of trees of associated species increases. This effect varies with site quality: on site III other species equal Douglas-fir in number at about 365 years; on site II, at 425 years. Beyond these ages, associated species surpass Douglas-fir in number.

This trend in species composition is borne out by data in table 1, which shows that mortality is heavier in Douglas-fir than in associated species. Sixty-one percent of total mortality is in Douglas-fir: 34 percent in trees over 40 inches d.b.h. and 27 percent in trees below 40 inches. For associated species, which account for 39 percent of mortality, only 10 percent is in trees over 40 inches and 29 percent in those under 40 inches. In other words, the understory of younger, more tolerant species, though losing some of its members, is gradually replacing the older, larger, and more defective Douglas-firs.

The probable trend in species composition is further elaborated in table 2, which shows response to release by species in old-growth Douglas-fir. Although these data were not obtained from undisturbed stands, the effect of partial cutting in releasing adjacent trees is similar to the effect of scattered individual trees dying in the stand. Isaac found

Table 2.--Effect of partial cutting on diameter growth of individual trees, based on radial growth 10 years before and 10 years after cutting

Species	Trees with-- Increased diameter growth	Trees with-- No change or decreased diameter growth	Total trees bored
	Number	Number	Number
Douglas-fir	72	157	229
Sitka spruce	29	45	74
Western hemlock	214	140	354
Western redcedar	46	35	81
Silver fir	21	10	31
Total	382	387	769

Source: Compiled from Isaac's table 3 (6).

that the older the tree, the less response it was likely to show to release. Douglas-fir, and Sitka spruce when present, made up the older age classes. Increment borings in all size classes of Douglas-fir and Sitka spruce showed that only a third of these trees responded to release. Two-thirds either showed no response or declined. On the other hand, 60 percent of the younger understory species (western hemlock, western redcedar, and silver fir) responded with accelerated growth; only 40 percent failed to respond.

Of the trees which did respond, 74 percent were understory trees containing relatively lower value wood. Only 26 percent were Douglas-fir and Sitka spruce, indicating that trend with advancing stand age ordinarily is toward a less desirable species composition from the standpoint of both value and regeneration of future stands.

Extent of brush encroachment. --A third criterion relating to quality of old-growth Douglas-fir stands is brush encroachment, the degree to which growing space has been taken over by brush. As stand age increases, holes in the stand canopy no longer close up as effectively as they normally would do in younger stands. Even in openings caused by loss of a single tree, conditions often change sufficiently so that brush development follows. As stand decadence proceeds and more openings appear, the percentage of growing space lost to brush increases, creating a number of silvicultural and regeneration problems.

Implications. --From the above discussion of stand quality and three criteria relating to this concept, one is led to conclude that decadent stands have the highest losses due to mortality and decay. These stands also tend to have more serious problems associated with brush encroachment and development of a less favorable species composition. Being high-risk stands, they should be favored for early clear cutting, markets permitting. If substantial delays are involved before final clear cutting, they would claim high priority for salvage of accumulated and current mortality. Otherwise, large per-acre losses would occur due to decay.

Cost of Salvage Logging

A good illustration of problems and costs encountered in salvage logging leave settings in old-growth Douglas-fir is found in reports by Carow and Ruth (4) and Carow (3). They describe an experiment at the H. J. Andrews Experimental Forest designed to (1) test a high-lead method for salvage logging in old growth using a mobile yarder, (2) measure logging costs and damage under this method, and (3) see how well the established road system would serve a salvage logging operation. This study isolates and sets forth three factors that are of prime importance as determinants of salvage-logging costs; namely, stand accessibility, salvable volume per acre, and topography.

Salvaging mortality on good topography near existing roads usually involves no problem other than possible damage to soil and remaining live trees. The need for consideration of such damage was pointed out by Isaac (6). On steeper ground and in areas not immediately accessible, however, utilization of dead and down material is not without specialized problems. In the experimental operation described by Carow and Ruth, avoiding damage to the reserve stand was a major consideration, and required limiting uphill yarding to short distances. Short yarding distances in turn necessitated intermediate spur roads, built to low standards and at minimum cost, to supplement the established main road system.

A net average of 14,700 board feet per acre was removed in this operation. Only dead and down trees--95 percent Douglas-fir by volume--were taken. How much of this volume was the current year's enphytotic mortality and how much was accumulated, undecayed dead material from past years is unknown. Log-selling values averaged $517 per acre, with stumpage bringing $186 per acre, or nearly $13 per thousand board feet.

An analysis of logging costs on this specialized operation indicates that they need not be much higher than for conventional high-lead clear cutting. Higher salvage-logging costs were offset by low road-construction costs. Also, certain other costs--depreciation and general and administrative expenses--were thought to be higher for this pilot study than would be expected after a crew had become accustomed to operating specialized equipment under restrictive conditions.

The H. J. Andrews study demonstrated that portable high-lead machinery could be adapted to yard dead-and-down material under old-growth stands on steep topography, minimizing soil disturbance and damage to remaining trees. More experience in all phases of this type of specialized operation may point the way toward reduced costs and damage from that found in this study.

The influence of stand accessibility, salvable volume per acre, and topography on cost of salvage logging is taken up in the following paragraphs.

Stand accessibility.--Salvage operations in stands adjacent to established roads ordinarily will not require large capital outlays for road construction. Some additional salvage roads may be required to put each point in an accessible stand within economic reach of logging equipment, but such additional roads may frequently be built to lower standards than main roads, minimizing this capital outlay. For inaccessible stands, capital requirements for building roads for as much as 5 to 50 years in advance of final clear cutting probably is the major deterrent to rapid development of programs to salvage enphytotic mortality. Accessible stands, then, will receive attention first.

Roads eventually will be built for the final clear cutting in presently inaccessible stands. But if roads can be built before final clear cutting, several benefits can be realized: (1) accumulated and subsequent enphytotic mortality losses captured; (2) catastrophic mortality from agents such as windthrow, insects, and disease salvaged more readily and resulting losses minimized; (3) fire protection and suppression activities facilitated; and (4) management planning made more flexible. In management planning, for example, high-risk stands can be selected for early harvest, and timber-sale planning and layout will be easier, thus reducing sale preparation costs.

Silen (7) reports how a complete road system in old-growth Douglas-fir on the H. J. Andrews Experimental Forest was planned in advance and designed to serve not only a mortality salvage program but also final clear cutting. Carow and Ruth (4) and Carow (3) describe how well this same road system served the experimental salvage operation in old-growth leave settings. Only 1.6 miles of low-standard spur road were needed in addition to the established permanent road system to put all down trees in the 111-acre experimental area within a 500-foot yarding distance. These spur roads will also serve for periodic recovery of mortality in the future. The H. J. Andrews study, and 4 preceding years of commercial salvage logging there, have demonstrated that a road system for periodic salvage of an entire reserve stand could be planned as part of the initial sale layout and that the salvage road system could be paid for as it was extended into the reserve stand.

Road building for salvage purposes needs careful scrutiny to determine what costs must be covered by returns from the salvage operation. At most, periodic salvage yields and associated benefits need only pay interest on the capital outlay and maintenance costs for a carefully planned permanent main road system, because the same road system would eventually have to be built for the final harvest. In addition, the salvage operation would have to meet the cost of any supplemental, low-standard roads needed only for salvaging mortality. Part of the initial capital outlay for advance roads would be recovered through depreciation allowances on right-of-way timber, the initial accumulated salvage, and subsequent periodic salvage yields. Thus, subsequent periodic salvage yields actually need to cover only interest charges on the undepreciated balance of the initial road outlay. The same roads will serve other purposes--such as access for protection against insects, disease, and fire--and these other purposes will help carry the interest charges and maintenance costs.

Salvable volume.--Salvage logging cost is directly influenced by per-acre volume of material available for removal. Logging cost per thousand board feet decreases as per-acre volume increases. Areas with heavy accumulations of dead and down timber and areas where future mortality may be heavy present the most attractive opportunities for high net returns per unit from a mortality salvage program (fig. 7).

Figure 7.--Accumulation of dead and down timber in an old-growth Douglas-fir stand. Some of this material is in advanced stage of decay.

Another factor related to salvage volume that helps reduce logging cost is size of log handled. Large logs are more economical to handle than small logs. An earlier section discusses tree size class and indicates that 89 percent of average annual enphytotic mortality is included in trees greater than 20 inches d.b.h.

Topography.--Steep or rugged terrain costs more to log than smooth ground that is level or gently sloping. Topography affects choice of logging method, which in turn affects road spacing and location, and hence logging costs. On relatively smooth ground that is not too steep, logging with tractors is preferable because optimum range of yarding distance ordinarily is greater for tractors than for high lead (7). A greater optimum range results in lower yarding costs and reduces capital outlays for roads. Steep, rugged slopes, however, are characteristic of most old-growth Douglas-fir stands, so tractor-logging chances are limited; portable high-lead systems will be required on most areas, or a combination of methods may be worked out using tractors on gentle slopes.

Choice among logging methods affects road location, since long uphill yarding distances and relatively short downhill distances are most advantageous for high lead, whereas just the reverse is desirable for favorable tractor logging. A road system for high lead, consequently, is oriented toward ridgetops and upper slopes; for tractor logging, roads follow creek bottoms and lower slopes. Since high lead requires closer road spacing, greater road mileage, and probable higher road construction costs per mile, road systems in old-growth Douglas-fir are likely to be more expensive for high lead than for tractor logging.

Value of Salvage Yield and Other Benefits

Value of salvage yield varies according to viewpoint of the evaluator. That is, an evaluator's identity will influence the manner in which he values yield from a mortality salvage program. Two viewpoints are recognized in this study: that of a seller of stumpage, and that of an integrated industrial operator who owns and harvests his own timber and also purchases stumpage or logs from other sources to supply his wood-using plants.

From a stumpage seller's viewpoint, the basic unit value he places on yield from a mortality salvage program is determined by the price he can get for salvage material. This price, in turn, is dependent upon cost of comparable wood to a prospective buyer after differences in conversion cost for alternative wood sources are taken into account.

An integrated operator will find it advantageous to substitute salvaged mortality for the most expensive wood he puts through his plant, irrespective of whether this wood is company owned or purchased. The object of such substitution is to maximize the value of salvage yield and, hence, net returns from the salvage program. Such substitution also minimizes current wood costs and increases total yields of the forest property. The basic net unit value of salvage yield for the integrated operator, therefore, is determined by the highest cost of other wood (delivered to the mill) for which salvaged mortality is substituted, less cost of recovering the mortality. Ordinarily, unit values will be higher and mortality salvage programs more profitable on company land for an integrated industrial operator than for a forest-land owner whose operation is confined to selling stumpage.

For both the stumpage seller and the integrated industrial operator, additional benefits that accrue from a mortality salvage program increase the basic value of salvage discussed above. The additional benefits previously listed in the section on stand accessibility arise when a road system for salvaging mortality is established in an inaccessible stand many years in advance of final clear cutting. Briefly, these benefits include cost savings in administration, management, and protection, and the opportunity to recover catastrophic losses that otherwise might have been inaccessible. A further consideration that enhances financial aspects of a

salvage program is the yield of green timber from the advance road right-of-way. This timber possesses a higher conversion surplus than other stumpage because yarding costs are not incurred; moreover, it contributes an immediate allowance for depreciation of the initial capital road outlay.

Assigning Priorities

Based on a consideration of the three criteria of stand quality--stand decadence, species composition, and brush encroachment--the manager of an old-growth property can identify low-vigor stands and schedule them for early clear cutting, if markets permit. In addition, vigorous stands can be ranked for initiation of periodic salvage operations. Ranking is done by comparing expected salvage logging cost with estimated value of salvage yield to identify those stands that promise highest profit opportunities from a periodic salvage program.

Ordinarily, stands will be assigned priorities as follows:

First. Accessible stands with high per-acre salvage volumes and values, relatively high vigor, and easy logging chances.

Second. Inaccessible stands with high per-acre salvage volumes and values, high expected rates of mortality, and easy road construction and logging chances.

Third. Accessible or inaccessible stands with low salvage volumes and values per acre but with good logging chances. When combined with rough terrain and high logging costs, stands with low mortality salvage values offer the least attractive prospects for salvage logging.

Exceptions to the foregoing precedence will be made for various reasons. Decadent stands which cannot be scheduled for immediate clear cutting because of unfavorable market conditions or other reasons, may claim special attention when priorities are assigned for salvage operations. The desirability of integrating salvage of catastrophic mortality with periodic salvage operations, or the need for building access roads for protection or administrative purposes might alter the above priorities. Such additional considerations, however, are peculiar to each individual property and cannot be fitted into a general classification. Effective handling of exceptional circumstances depends upon the ability of the forest manager to synthesize each element into an old-growth management program that seeks to maximize net returns for the owner.

CONCLUSION

In the past, the idea has often been advanced that old-growth Douglas-fir stands should be preserved as long as possible to provide high-grade timber during the time when more and more young growth is being harvested. The substantial gross growth sometimes found in these old-growth stands and the possibility of periodically salvaging enphytotic mortality appears to lend support to this view. However, preserving old-growth Douglas-fir stands over too long a period may result in a rapid drop in stand quality due to loss of the Douglas-fir component through decay and decadence, thereby contributing to formation of a climax type composed of the younger understory of less desirable species and to a loss of growing space to brush.

On the other hand, it is sometimes advocated that old-growth Douglas-fir stands should be liquidated as rapidly as is consistent with sustained yield principles in order to make room for young, vigorous stands. This view is based on the belief that old-growth stands eventually quit growing and begin to deteriorate. But this is an oversimplification. What actually happens is that annual mortality approximates or exceeds annual gross growth, causing net growth to be either very small or negative. Liquidation may therefore be unsound if based solely on the misconception that no growth is occurring.

In the Douglas-fir subregion, old-growth types other than Douglas-fir (fig. 8) aggregate an additional 3 million acres. Mortality in these

Figure 8.--Old-growth types other than Douglas-fir are ripe for initiation of mortality salvage programs: A, western hemlock, with some Douglas-fir and Sitka spruce; B, Sitka spruce on the Oregon coast; C, true fir–mountain hemlock type, with noble fir predominant.

old-growth types has not yet been investigated; research is needed here to further enlarge opportunities for increasing the Nation's timber supply.

So long as sustained yield principles are practiced, old-growth stands will continue to be logged in the Douglas-fir subregion for 50 years or more, whether a policy of preservation or liquidation is followed. Conservation in use of the timber resource and the economics of forest-land management indicate that a salvage program for capturing enphytotic mortality is an integral part of sound old-growth management programs.

LITERATURE CITED

1. Berntsen, Carl M.
   1960. Productivity of a mature Douglas-fir stand. U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Note 188, 4 pp., illus. (Processed.)

2. Boyce, John S., and Wagg, J. W. Bruce.
   1953. Conk rot of old-growth Douglas-fir in western Oregon. Oreg. Forest Prod. Lab. Bul. 4, 96 pp., illus.

3. Carow, John.
   1959. Yarding and loading costs for salvaging in old-growth Douglas-fir with a mobile high-lead yarder. U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Paper 32, 26 pp., illus. (Processed.)

4. Carow, John, and Ruth, Robert H.
   1957. Mobile yarder shows promise in salvage. The Timberman 58(10): 66-69, 104, 108; illus.

5. Childs, T. W., and Clark, J. W.
   1953. Decay of windthrown timber in western Washington and northwestern Oregon. Bur. Plant Indus., Soils, & Agr. Engin. Forest Path. Spec. Release 40, 20 pp., illus.

6. Isaac, Leo A.
   1956. Place of partial cutting in old-growth stands of the Douglas-fir region. U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Paper 16, 48 pp., illus. (Processed.)

7. Silen, Roy R.
   1955. More efficient road patterns for a Douglas-fir drainage. The Timberman 56(6): 82, 85-86, 88; illus.

8. Steele, Robert W., and Worthington, Norman P.
1955. Increment and mortality in a virgin Douglas-fir forest. U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Note 110, 6 pp., illus. (Processed.)

9. U.S. Forest Service.
1958. Timber resources for America's future. Forest Resource Rpt. 14, 713 pp., illus.

10. Wright, Ernest, and Wright, K. H.
1954. Deterioration of beetle-killed Douglas-fir in Oregon and Washington: a summary of findings to date. U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Paper 10, 12 pp., illus. (Processed.)

11. Wright, K. H., and Lauterbach, P. G.
1958. A 10-year study of mortality in a Douglas-fir sawtimber stand in Coos and Douglas Counties, Oregon. U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Paper 27, 29 pp., illus. (Processed.)

GPO 995309